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Potato Virus Disease Studies With Tuber-Line Seed Plots and Insects in Maine 1927 to 1938

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BULLETIN 410

POTATO VIRUS DISEASE STUDIES WITH TUBER-LINE SEED PLOTS AND INSECTS IN MAINE 1927 to 1938

Donald Folsom

INTRODUCTION

In 1922, the potato virus diseases mild mosaic and leafroll recently had been proved to be transmitted by insects, and spindle tuber was found to be another virus disease. It was soon demonstrated that these three diseases reduced the yield rate and quality of Maine potatoes and that they spread from one hill to another, from one row of plants to another, and from one potato field to another *(8)*.[1] It was shown that in Maine the virus diseases introduced into healthy plants usually are not apparent until the next generation of plants is grown.

The discovery of insect transmission of potato virus diseases was the basis for beginning certain seed-plot work in 1921. Although spindle tuber, according to surveys, was present in about half of the potato plants in Aroostook County in 1922 and 1923, within a few years it had been practically eliminated as an important factor in Aroostook potato growing. This was accomplished by the cooperative use of the best available seed stocks. Therefore spindle tuber soon became less important than mosaic and leafroll in the seed-plot work.

The results of the seed-plot work were summarized in part in 1926 *(9)*, in 1934 *(16)*, and in 1940 *(20)*. With respect to the studies upon which those several reports were based, the studies to be described in this bulletin are somewhat different. The latter had as their chief objects the testing of the healthy tuber-line as a means of controlling potato virus diseases, the determination of the frequency of spread of disease from one field or plot to another, and the determination of the effects of certain general conditions upon the success of seed plots over the entire State.

A tuber-line is a stock or clone of potatoes known to have been recently increased from one original tuber or part of a tuber. If a tuber-line is planted two or more successive years under an

[1] Italic numbers in parentheses refer to Literature Cited, p. 249.

insect-proof cloth cage without showing the symptoms of a certain virus disease, it may be considered healthy with respect to that disease. That is, providing climatic conditions are at the same time favorable to the expression of the symptoms of the disease in affected tuber units.

At first the writer hoped that healthy tuber-lines could be increased in size in comparatively well isolated plots without becoming affected to any extent by the virus diseases already mentioned. Encouraging results were reported by Kotila from northern Michigan from the use of tuber-lines *(12; 11)*. In about 1923, some unusually good Spaulding Rose and Irish Cobbler seed stocks in Aroostook County were claimed by the owners to have originated as tuber-lines. About 1926, a farmer near Lee showed that tuber-line Green Mountain stocks could be increased for a few years without disease entering them. In Washington County, seed stocks produced in small insect cages remained healthy in the open until they had been grown near to partly diseased stocks.

The ultimate failure of these efforts, and other observations that will be described later, led to the second phase of the studies, wherein an attempt was made to determine to some extent the frequency of the passage of disease into healthy tuber-line plots. Only in this way could field-to-field transmission be adequately studied. Tuber-line plots were the only kinds free of mosaic. In any plot already containing some diseased hills, one could not be certain that any disease increase could be attributed to entrance from other fields as distinguished from transmission from one hill to another within the plot.

A third phase was concerned with the effects of various conditions upon disease invasion of seed stocks in tuber-line plots. From 1927 to 1938, inclusive, 135 seed plots were planted with Green Mountain tuber-line stocks originated on Highmoor Farm. The general effects of latitude, earliness of planting and development of plants, size of seed plot, and so-called isolation upon the passage of disease into the plots and upon the increase of disease within the plots were studied. Incidentally, also, the efficiency of large aster-cloth cages *(5)* and the helpfulness of tuber-unit planting[2] in detect-

[2] "Tuber-unit planting" is characterized by all seed pieces cut from a given tuber being planted in succession along the row before the pieces from the next tuber are planted.

ing disease were demonstrated. The relative dangerousness of certain insects also was studied in cage experiments with leafroll and in the field using insect counts,

In originating tuber-lines, it has been considered important that they might vary, even when healthy, with respect to tuber type and yielding capacity. A study reported upon in 1931 *(7)* showed that usually any healthy strain or tuber-line was like any other in type and yield rate when grown under similar conditions of soil, weather, etc. In view of the possibility of occasional exceptions to this rule, a comparison was made in 1934 between five tuber lines (10, 301, 302, and 303 of Table 1, and one originated by a seed grower). In this comparison no significant differences were found *(3)*. The yield rate was 171 barrels (470 bushels) an acre and more, the range being no more than that secured in 1933 between parts of the same tuber-line grown on the same ground but coming respectively from seed grown on different farms.

On the other hand, during the roguing of hundreds of thousands of hills, the writer observed about one hill in every 40,000 to be a sport with respect to color, form, and hairiness of foliage. Such sports reverted to normal form wholly or in part when perpetuated through one or more generations. One, however, maintained its abnormal form (Plates 1-3) in enough of its progeny to permit a replicated yield test in 1933 *(4)*. With the original line yielding 129 barrels (355 bushels) an acre, the sport form of leaf reduced the yield 18 per cent, with odds significant, while the reverted part of the tuber-line yielded about the same as the original.

Altogether, the evidence indicates the possibility of tuber-lines being different in yielding capacity and tuber type, but also indicates that the odds are heavily against it and that when a tuber-line has been multiplied to several hundred tubers, it will not change inherently to any appreciable extent in these respects except through the entrance of disease.

TUBER-LINES ON HIGHMOOR FARM TO 1932 INCLUSIVE

At Highmoor Farm, in southwestern Maine, tuber-unit plots from 1924 to 1927 were somewhat encouraging, inasmuch as their use eliminated mosaic and leafroll from seed stock.

From 1927 to 1932, inclusive, both partly diseased fields and healthy tuber-lines were planted on Highmoor Farm. The diseases in each partly diseased field consisted of one or more of the following: mild mosaic, rugose mosaic, leafroll, spindle tuber, and yellowtop[3]. Each instance of an exposure to one of these diseases of a tuber-line that was healthy with respect to the disease in question, is recorded in Table 1 with the distance between the diseased plants and healthy tuber-line. Whether or not the disease entered the tuber-line, or how much, was learned the next year from the young plants. This also is recorded in Table 1.

The data in Table 1 include 19 exposures of a mild-mosaic-free tuber-line to mild mosaic on the same farm, 13 similar exposures to rugose mosaic, 15 to leafroll, 19 to spindle tuber, and 9 to yellowtop. The total was 75 exposures or chances for one or another particular disease, of the five listed, to enter a tuber-line seed plot still free of the disease. If all the 21 tuber-line seed plots had been entirely healthy and the diseased field had contained all five diseases each year, there would have been 21 exposures of a healthy plot to each disease, or a total of 105 exposures instead of the 75 actually occurring.

The figures in Table 1 show that out of the 75 chances in 21 seed plots, a tuber-line became newly infected by a virus disease to some extent in 15 instances, sometimes in spite of isolation of ¼ to over ½ mile. Nearly half of the 15 instances of original disease dissemination were of leafroll, and leafroll in 6 instances entered a tuber-line enough to result in about 2 per cent or more infection. There was an instance of infection when the tuber-line was isolated at least ¼ mile, with respect to every one of the five virus diseases.

On this farm there were practically no weeds of the botanical family containing the potato, and no biennial or perennial weeds or crop plants known to harbor any potato virus. Several wild individuals of bitter-nightshade *(Solanum Dulcamara)* were kept under observation but showed no symptoms of virus diseases or aphid infestation (see *1*, p. 23-24). It was (and is) thought that

[3] Described by Whipple (*24*, figs. 2-4 and text pp. 8-12) and by Folsom (*6*, p. 23 and Fig. 6). Said by Schultz to be similar to apical leafroll (see *15*). Also similar to descriptions of potato witches' broom (*10; 25*) and of potato infected with western aster yellows (*19*).

TABLE 1

Infection by virus diseases occurring in healthy tuber lines grown at different distances from diseased plants on Highmoor Farm, 1927 to 1932

Disease	Year	Tuber-line	Tuber-line size	Distance from diseased plants	Diseased plants	Infection occurring in tuber-line[1]
				Feet		Per cent
Mild mosaic	1927	1	12 hills	4700	2640	0
		2	13 “	4750	2640	0
		3	9 “	4350	2640	0
		4	12 “	4350	2640	0
		6	8 “	5050	2640	0
		9	9 “	5050	2640	0
		10	9 “	5050	2640	0
	1928	1	420 “	440	20(r)[2]	0
		10	270 “	3000 140	2100 20(r)	0
	1929	10	¼ acre	1300	350	0.2
	1930	301	10 hills	2800 3000	20(r) 300	0
		302	10 “	2800 3000	20(r) 300	0
		303	10 “	2800 3000	20(r) 300	0
	1931	301	120 “	2850	12(r)	0
		302	120 “	2100	12(r)	0
		303	220 “	1650	12(r)	0
	1932	301	1/10 acre	2850	8(r)	0
		302	1/6 “	2100	8(r)	0
		303	1/6 “	1500	8(r)	0.05
Rugose mosaic	1927	1	12 hills	4700	220	0
		2	13 “	4750	220	0
		3	9 “	4350	220	0
		4	12 “	4350	220	0
		6	8 “	5050	220	0
		9	9 “	5050	220	0
		10	9 “	5050	220	0
	1928	1	420 “	2580	700	0
		10	270 “	2800	700	0
	1929	10	¼ acre	1300	450	0.2
	1930	301	10 hills	2800 3000	20(r) 600	0
		302	10 “	2800 3000	20(r) 600	0
		303	10 “	2800 3000	20(r) 600	0
Leafroll	1927	1	12 “	4700	800	10[3]
		2	13 “	4750	800	28[3]
		3	9 “	4350	800	68[3]
		4	12 “	4350	800	0
		6	8 “	5050	800	0
		9	9 “	5050	800	0
		10	9 “	5050	800	0
	1928	10	270 “	3000 140	1300 220(r)	0
	1929	10	¼ acre	1300 100	230 585(r)	2
	1930	301	10 hills	2800 3000 1500	460(r) 1100 v[4]	0
		302	10 “	2800 3000 1500	460(r) 1100 v[4]	0
		303	10 “	2800 3000 1500	460(r) 1100 v[4]	0

[1] Amount occurring in one year was not evident until after tuber perpetuation. For example, mild mosaic infection occurring in 1929 in the ¼ acre was not evident until the next crop was grown in 1930.
[2] “r” indicated that the diseased hills were rogued.
[3] Possibly from a nearby field on another farm.
[4] “v” denotes volunteers, uncounted but not numerous.

TABLE 1—(Continued)

Disease	Year	line Tuber-	size Tuber-line	Distance from diseased plants	Diseased plants	Infection occurring in tuber-line[1]
				Feet		Per cent
	1931	301	120 "	2850	220(r)	1.7
		302	120 "	2100	220(r)	1.9
		303	220 "	1650	220(r)	0.1
Spindle tuber	1927	1	12 "	4700	215	0
		2	13 "	4750	215	0
		3	9 "	4350	215	0
		4	12 "	4350	215	0
		6	8 "	5050	215	0
		9	9 "	5050	215	0
		10	9 "	5050	215	0
	1928	1	420 "	440 2580	30(r) 420	0
		10	270 "	140 2800	30(r) 420	0
	1929	10	¼ acre	1300	250	0
	1930	10	¾ "	1300	420	0.05
		301	10 hills	3000	420	0
		302	10 "	3000	420	0
		303	10 "	3000	420	0
	1931	301	120 "	2850	12(r)	0
		302	120 "	2100	12(r)	0
		303	220 "	1650	12(r)	0
	1932	301	1/10 acre	2850	55(r)	0
		302	⅛ "	2100	55(r)	0
Yellowtop[5]	1928	1	420 hills	440	2(r)	0
		10	270 "	140	2(r)	0
	1929	10	¼ acre	1300	13	0
	1931	301	120 hills	2850	24(r)	0
		302	120 "	2100	24(r)	0
		303	220 "	1650	24(r)	0.7
	1932	10	2 acres	1500	14(r)	0.03
		301	1/10 acre	1600	14(r)	0.1
		302	⅛ "	1050	14(r)	0.1

[5] Described by Whipple (24, figs. 2, 3, and 4, and text pp. 8-12) and by Folsom (6, p. 23 and fig. 6). Said by Schultz to be very similar to apical leafroll (see 15). Also similar to descriptions of potato witches' broom (10; 25) and of potato infected with western aster yellows (19).

the most probable cause of tuber-line infection was insects bearing virus from other potatoes grown either on this farm or on other farms.

Accidental mixing of other potatoes in these tuber-lines was prevented by the practices (1) of sacking them in the field the first year when they consisted of a few hills, (2) of placing them in barrels, when the lots were larger, and then closing the barrels in the field immediately by means of wire covers or wooden heads, and finally (3) of postponing the opening of the containers in the spring until they had been taken into the field at the time and place of planting operations.

These studies on Highmoor Farm were supplemented by observations in Penobscot County. In 1931 about 40 small Green

Mountain tuber-unit seed plots were planted by farmers from seed good enough so that 12 plots had no mosaic. The crops from 10 of the 12 were replanted in 1932 and all these 10 stocks showed mosaic. Available records as to isolation and results of mosaic invasion are:

Isolation in 1931	Mosaic per cent in 1932
Half mile from highly mosaic stock to S.E.	About 0.5
2000 ft. from any other potatoes	About 1
1200 ft. from mosaic stock to N.E.	About 1
500 ft. from 80 per cent mosaic stock to S.W.	About 2

The results showed that a half-mile isolation would not necessarily or always keep away mosaic. However, they showed also that with a good source of seed it was possible for some farmers to grow certifiable stock in their own seed plots.

TUBER-LINES AND LARGE CLOTH CAGES ON HIGHMOOR FARM 1933 TO 1937

The experiments at Highmoor Farm and observations elsewhere led the writer to extend the study of tuber-line plots to more potato-growing parts of the State and especially to Aroostook County. The foundation stock was to be developed each year at Highmoor Farm. However, a tuber-line that had been originated on Highmoor Farm in 1930 was found to have traces of mosaic, leafroll, and yellowtop when planted there in 1933. Therefore the type of aster-cloth cage that had been developed for keeping virus-transmitting insects away from asters was adopted for a small seed plot on Highmoor Farm (Plate 4).[4] At Highmoor Farm the purpose of using a cage was to protect tuber-line stock from virus diseases until there was enough healthy stock to plant four acres on the Farm in the open. The crop from the four acres had much less virus introduced into it, on the basis of the percentage of hills

[4] It was not expected that potato growers could afford to use such a cage, but nevertheless at least one (the grower of one of the largest tuber-unit acreages in the State, averaging around 100 acres a year) has found a cage profitable through its greatly reducing the amount of roguing necessary in stock as grown in the open the second year away from the cage.

infected, than smaller plots. The crop from the four acres was then sold to interested farmers. The general sequence was as follows:

(1) 1933, 3/10 of one acre planted by tuber units in aster-cloth cage on Highmoor Farm.
(2) 1934, crop from the 1933 cage (except for some re-planted in 1934 cage) grown in the open in four acres planted by tuber units on Highmoor Farm.
(3) 1935, crop from the 1934 uncaged field on Highmoor Farm grown by farmers in seed plots.
(4) 1936, crops from the farmers' 1935 seed plots mostly replanted by the same farmers in plots and fields, and wherever planted, if in Maine, examined early for tuber-perpetuated mosaic and leafroll resulting from insects bringing in and spreading these diseases during 1935.

TABLE 2

Comparison of infection occurring under the aster-cloth cage and in the open at Highmoor Farm, and in the open in farmers' seed plots, in tuber-line Green Mountain potatoes

Series	Mosaic infection[1]			Leafroll infection[1]		
	Caged at H. F.	Uncaged at H. F.	Farmers' seed plots[2]	Caged at H. F.	Uncaged at H. F.	Farmers' seed plots[2]
1933-36	None	2.3[3]	31	None	4	39
1934-37	None	None	82	None	11	7
1935-38	None	1.4	126	2[4]	15	808
1936-39	None	1.1	6	2[5]	26	100

[1] Amount occurring in one year was not evident until after tuber perpetuation. For example, leafroll infection occurring in 1935 in the cage was not evident until the next crop was grown in 1936, and new infection occurring in the rogued uncaged Highmoor Farm field in 1936 was not evident until the next crop was grown in farmers' fields in 1937.

[2] Only those with none of the disease present at the beginning of the season, perpetuated by the seed tubers.

[3] All figures are hills per 10,000, or in slightly less than an acre. 2.3 per 10,000 would be 0.023 of one per cent.

[4] The erection of the cage in 1935 had to be postponed because of the nature of the weather until some potato plants had emerged from the soil. This permitted a few aphids to reach the plants before they were protected, with two tubers becoming infected as the result.

[5] Unavoidable conditions again prevented the erection of the cage until a few plants had emerged. This permitted a few aphids to begin an infestation. In addition, imperfections in the cloth permitted further infestation by aphids through gaps. However, only one tuber became infected.

This 1933-36 series was overlapped by a 1934-37 series, a 1935-38 series, and a 1936-39 series, each with the same sort of general sequence. A comparison of the infection in the caged plot, in the open at Highmoor Farm, and in the open on other farms, is given in Table 2. The figures in Table 2 show that very little infection occurred in the caged plot even when the cage was erected too late to exclude all aphids. (A well-sheltered location is necessary for the best results with such a cage, to prevent disastrous damage by wind during erection of the cage. In the Highmoor Farm location, wind sometimes delayed an attempt to erect the cage.) Usually some mosaic was brought by insects into the healthy uncaged fields at Highmoor Farm, and always some leafroll. However, the amount was smaller than most of the average disease figures given for insect infection of the originally healthy seed plots grown by farmers. This indicates that probably the chances to get originally healthy farmers' seed plots to study were increased greatly by using the isolation of Highmoor Farm and by having the farmers' foundation stock at Highmoor Farm kept nearly disease-free by annual replenishment from the cage.

There may be some question of the reliability of the replanting by the farmers in the last stage of the sequence. However, each grower was anxious to keep the obviously desirable Highmoor Farm stock from becoming adulterated with other stocks, and probably any slight admixtures that may have occurred did not appreciably affect the disease percentages or the reliability of the general conclusions drawn from the study as a whole.

FARMERS' TUBER-LINE SEED PLOTS 1933 TO 1938

GENERAL PROCEDURE

Tuber-line stocks grown on Highmoor Farm in the open in 1932 (10, 301, and 302 of Table 1) were planted in 1933 by farmers except for one plot on Aroostook Farm. The farmers' plots were rogued by the writer and the Aroostook Farm plot by others at least as well qualified. There were 19 plots; the crop from each of 18 of these was replanted separately in 1934. The replanted stocks were examined for virus diseases in 1934 and the readings used for comparisons as to the effect of various conditions in 1933.

The tuber-line (303) grown on Highmoor Farm in the open in 1933 was planted in 1934 by farmers, but all the plots were found to contain some mosaic and therefore were not studied further, as the main object at that time was to study the invasion of healthy plots by mosaic.

As indicated in the previous section of this bulletin, seed stock grown on Highmoor Farm in the open from 1934 to 1937 inclusive was grown each year from seed raised under a large aster-cloth cage. In turn it was replanted by a number of farmers in seed plots of which most were rogued by the writer and the rest by W. F. Porter. In 1935 and thereafter the Highmoor Farm seed plots not under cage were included with the farmers' plots in the study of the effect of various conditions upon the success of seed plots. Some farmers' seed plots, especially in 1938, were planted with seed stock more than one year removed from Highmoor Farm but still good enough to be included in the study of the effect of conditions.

In 1935 there were 29 seed plots, the crops of which were replanted and examined. In 1936 there were 26 with the crop of each replanted; in 1937, 27; and in 1938, 14. The 1937 plots included 16 in Aroostook County.

The records on disease content of the seed plots and of the replanted seed stocks were analyzed to determine the effect of various conditions upon the effectiveness of the seed plots. The work of each year has been reported in the appropriate annual report of this Station. Here it is possible to discuss the results of the several years' work with respect to each of the various conditions studied.

FREQUENCY OF THE ENTERING OF HEALTHY SEED PLOTS BY VIRUS DISEASES

When a seed plot and the replanted stock both had a disease, obviously it could not be proved that the disease had entered the seed plot from outside. When a replanted seed stock contained a disease that the seed plot had been free of, it was considered that the disease had entered the seed plot. When a disease had been rogued out of a seed plot and had not appeared in the replanted

stock, it was considered that the disease had not entered the seed plot during the growing season.

TABLE 3

Proportion of farmers' tuber-line plots 1933 to 1938 with disease entering from other fields

Years	Healthy plots with mosaic entering	Plots remaining free of mosaic	Plots losing their mosaic	Healthy plots with leafroll entering	Plots remaining free of leafroll	Plots losing their leafroll
1933	12	0	0	3	1	0
1935	5	9	5	5	6	2
1936	18	5	0	3	4	9
1937	6	9	3	5	0	0
1938	2	7	2	1	0	0
1933-38	43	30	10	17	11	11

As is shown in Table 3, there were 83 seed plots with respect to which it could be proved that mosaic[5] either did or did not enter; the disease came into 43 of these 83. There were 39 plots where it could be proved that leafroll either did or did not enter; the disease came into 17 of these 39. The corresponding figures for yellowtop were only 3 invasions out of 108 chances, and by spindle tuber there was only 1 invasion out of 109 chances.

Effect of Tuber-Unit Planting

Contrary to what might be expected, the advantages of tuber-unit planting were not the explanation of the differences between the three classes of plots listed in Table 3. Of the healthy plots contracting mosaic, 63 per cent were tuber-unit while only 40 per cent of the others, in either class, remaining free of mosaic or losing their mosaic, were tuber-unit. Of the healthy plots acquiring leafroll, 59 per cent were tuber-unit, while only 40 and 45 per cent were tuber-unit in the other two classes.

The tuber-unit method of planting was used in less than half of the acreage in seed plots. As is shown in Table 4, tuber-unit planting permitted up to 3 times as many hills to be rogued for

[5] Mostly mild mosaic.

TABLE 4

Tuber-unit vs. bulk planting for effectiveness in roguing in farmers' seed plots[1]

Year	Total hills[2] Tuber-unit	Total hills[2] Bulk	Mosaic Tuber-unit	Mosaic Bulk	Mosaic Ratio of percentages	Leafroll Tuber-unit	Leafroll Bulk	Leafroll Ratio of percentages	Yellowtop Tuber-unit	Yellowtop Bulk	Yellowtop Ratio of percentages
			Per cent	Per cent		Per cent	Per cent		Per cent	Per cent	
1933	—[3]	—	—[4]	—	—	0.15	0.03	5.0:1	0	0	—
1934	—[5]	—	0.14	0.10	1.4:1	0.23	0.09	2.6:1	0	0	—
1935	160,000	280,000	0.01	0.01	1.0:1	0.05	0.02	2.5:1	0.01	0.01	1.0:1
1936	80,000	70,000	0	0	—	0.16	0.10	1.6:1	0	0	—
1937	90,000	230,000	0.03	0.01	3.0:1	0.24	0.12	2.0:1	0.03	0.02	1.5:1
1938	70,000	110,000	0.02	0.01	2.0:1	0.44	0.20	2.2:1	0	0	—

[1] Only those comparable; first year removed from Highmoor Farm and rogued mostly by the writer, the rest by W. F. Porter.
[2] Based fundamentally upon row counts, and hill counts in representative rows, in the individual plots. Total for all plots then changed to nearest multiple of 10,000.
[3] Number of hills not estimated; comparison based upon 16 plot readings.
[4] Not enough disease to justify comparisons.
[5] Number of hills not estimated; comparison based upon 11 plot readings.

mosaic, up to 5 times as many for leafroll (averaging over twice as many), and up to 1.5 times as many for yellowtop, as in bulk-planted parts of the same seed stock. More frequent roguings and much slower roguing than were possible in these studies might have reduced this difference somewhat. However, even so, it is believed that under the best conditions it is difficult to find all diseased hills when not in tuber units. In mixed planting after the first roguing or two it is impossible to find all leafroll-hills without handling every hill individually. There are usually at least 12,000 hills per acre.

It was expected that bulk planting would increase the difficulty of finding diseased hills. It was also expected that this would favor the success of tuber-unit plots. Consequently it was a surprise to learn early in the history of the project that certain other conditions often overshadowed the effect of tuber-unit planting, as will be shown later. Because of this discovery it was considered unwise to limit the Highmoor Farm foundation seed to growers who would tuber-unit it. In fact, in some years it would have been impossible with such a requirement to sell the seed at a reasonable price. Further, in these studies the small amount of disease present in most years apparently made negligible the effect of bulk planting upon the effectiveness of roguing. Many plots had no

disease present anyhow, and the greatest difference from bulk planting, namely, 0.24 per cent leafroll in 1938, was only about 30 rogued hills an acre. In this instance, in the replanted stocks from the 1938 plots there were about 695 hills leafroll per acre from tuber-unit plots and about 565 hills leafroll per acre from bulk-planted plots which were less thoroughly rogued.

TABLE 5

Effect of tuber-unit vs. bulk planting of seed plots

Year	Number of plots		Disease in replanted seed stocks[1]				Remarks
			Mosaic		Leafroll		
	Tuber-unit	Bulk-planted	Tuber-unit	Bulk-planted	Tuber-unit	Bulk-planted	
			Per cent	Per cent	Per cent	Per cent	
1933	12	6	2.05	0.82	1.07	0.43	
1935	12	17	0.31	0.15	0.39	0.79	Tuber-unit plots more in the northeast
1936	12	14	1.28	0.54	0.07	0.51	Tuber-unit plots mostly in Aroostook County
1937	12	15	4.46	2.23	9.25	8.89	Ditto
1937 (Aroostook only)	9	7	5.94	4.77	12.28	9.20	Bulk plots larger
1938	7	7	0.50	0.09	5.79	4.71	Bulk plots mostly outside Aroostook County

[1] Averages for the groups of plots.

As is shown in Table 5, a total of 114 plots was about evenly divided between tuber-unit and bulk-planted. In all yearly comparisons except two for leafroll, the tuber-unit seed stocks when replanted had a higher average percentage of disease than the bulk-planted. No annual comparison gave a significant difference, but the trend is unmistakable and for the State as a whole the ratios are from 2 to 1 for 1937 up to 5 to 1 for 1938 in mosaic with more in the tuber-unit stocks. Student's method shows a significant difference for the series of years with respect to mosaic.

The apparently unfavorable effects of tuber-unit planting do not contradict the well-known principle that with all conditions equal it is better to plant by tuber units, but they show that certain other conditions sometimes may have more effect upon the success of seed plots than the method of planting. That is, the association

of poor results with tuber-unit planting in these studies is not to be considered as evidence in favor of bulk planting over tuber-unit planting, but rather as evidence that tuber-unit planting likely may be wasted effort when done late and in small fields, unless the isolation is greater than the majority of the potato growers in Maine can accomplish.

EFFECT OF DISEASE-CONTENT IN SEED PLOTS

Any apparent effect of variation in amount of disease percentage in the seed plot upon disease percentage in the replanted seed stock was absent in the case of mosaic in 1933 and leafroll in 1933 and 1936 (Table 6). Significant correlation indicated a positive effect in the case of leafroll in Aroostook County in 1937 and mosaic in 1938. In these two instances there probably was enough spread within the seed plots from diseased hills before such hills were rogued out, to overshadow the effect of other conditions. This might be surprising in view of the small percentage of disease (Table 4); there were 0.24 per cent leafroll and 0.02 per cent mosaic for averages of tuber-unit plots. However, Simpson *(21)* has reported evidence of considerable early spread of leafroll in Aroostook County in 1937.

TABLE 6

Effect of disease-content in seed plots

Year	Correlation (r) between disease percentage in seed plot and in replanted seed stock[1]	
	Mosaic	Leafroll
1933	—.054[2], not significant[3]	—.056, not significant
1935	+.230, not significant	+.034, not significant
1936[4]	——	—.224, not significant
1937	+.263, not significant	+.138, not significant
1937 (Aroostook only)	+.088, not significant	+.588, significant
1938	+.987, highly significant	+.380, not significant

[1] Replanted seed stock examined in year after that given for the seed plot.

[2] +1.000 would mean that disease percentages in the seed plots were perfectly proportional to disease percentages in the respective replanted seed stocks, both larger at the same rate, while —1.000 would mean that one was greater while the other was less in perfect proportion. To be considered significant, the figure must be of a certain size depending upon the number of comparisons.

[3] Significance based upon section 5 and table 16 of Wallace and Snedecor (22), in this and following tables.

[4] No mosaic this year in seed plots planted directly from Highmoor Farm.

EFFECT OF REGION ON SUCCESS OF SEED PLOTS

The plots in 1933 were all in Aroostook County. With reference to Caribou, 6 plots were situated to the west, 6 to the southwest, and 5 to the southeast. These three groups as listed showed progressively less mosaic and less leafroll in the replanted seed stocks, averaging respectively 2.28, 1.90, and 0.82 per cent mosaic and 1.77, 0.69, and 0.28 per cent leafroll. The differences were not significant and may have been due to conditions other than location.

TABLE 7

Effect of distance of seed plots from Kittery[1]

Year	Correlation (r) between miles from Kittery and disease percentage in replanted seed stock	
	Mosaic	Leafroll
1935	+.442, significant	—.395, significant
1936	+.735, highly significant	—.606, highly significant
1937	+.428, significant	+.270, not significant
1937 (Aroostook only)	+.083, not significant	—.167, not significant
1938	—.215, not significant	—.639, highly significant

[1] Extreme southwestern town of Maine.

In the following years, according to data given in Table 7, there was usually more mosaic in the replanted seed stocks according to the distance of the seed plots from Kittery (the town in the extreme southwestern corner of the State), and usually less leafroll. That is, the further the seed plot toward the northeast, the

TABLE 8

Effect of region upon disease percentages in replanted seed stocks

Year	Mosaic			Leafroll		
	Aroostook	Outside Aroostook	Significance of difference	Aroostook	Outside Aroostook	Significance of difference
	Per cent	Per cent		Per cent	Per cent	
1935	0.61	0.014	Yes	0.023	0.94	Yes
1936	1.29	0.22	High	0.04	0.73	No
1937	5.43	0.001	High	10.92	6.34	No
1938	0.14	0.38	No	1.58	7.47	Yes

less chance to get a low mosaic reading and the greater chance to get a low leafroll reading in the replanted seed stock.

Following this further, it was found that Aroostook seed plots usually were less successful as to mosaic control and more successful as to leafroll control than were plots located south and west of Aroostook (Table 8). Considering the ratio of percentage of disease in the seed plot to that in the replanted seed stock (Table 9), mosaic multiplied more in Aroostook than elsewhere

TABLE 9

Effect of region upon increase of virus disease percentage[1]

As seed plots						Replanting				Ratio of 2 years' percentages		
Year	Region	No.	Mosaic	Leaf-roll	Yellow-top	Year	Mosaic	Leaf-roll	Yellow-top	Mosaic	Leaf-roll	Yellow-top
			Per cent	Per cent	Per cent		Per cent	Per cent	Per cent			
1933	Aroostook	18	.034	.229	.053	1934	1.639	.912	0	1:48.2	1:4.0	—
1935	Aroostook	10	.026	.053	0	1936	.610	.023	0	1:23.5	2.3:1	—
	Patten	3	.017	.063	0		.023	.053	0	1:1.4	1.2:1	—
	Aroostook and Patten	13	.024	.055	0		.475	.030	0	1:19.8	1.8:1	—
	Outside Aroostook and Patten	14	.018	.028	0		.009	1.154	0	2.0:1	1:41.2	—
1936	Central Aroostook	12	0	.081	0	1937	1.343	.005	0	—	16:1	—
	Southern Aroostook	4	0	.140	0		1.150	.150	0	—	1:1.1	—
	All Aroostook	16	0	.096	0		1.294	.041	0	—	2.34:1	—
	Outside Aroostook	10	0	.026	0		.224	.726	0	—	1:28	—
1937	Aroostook	16	.040	.183	.036	1938	5.43	10.92	0	1:136	1:59.7	—
	Outside Aroostook	11	.0025	.076	.005		.0009	6.34	.007	2.8:1	1:83.4	1:1.4
1938	Aroostook and Patten	7	.012	.291	0	1939	.100	1.53	0	1:8.3	1:5.3	—
	Outside Aroostook and Patten	7	.101	1.323	0		.486	8.97	0	1:4.8	1:6.8	—

[1] Averages for groups of seed plots and their replanted crops.

in 1935, 1937, and 1938, or including all the years when such a comparison was possible, while leafroll multiplied less in Aroostook than elsewhere in 1935, 1936, 1937, and 1938, or again in all the years when comparisons were possible. For example, in 1937 leafroll increased 60-fold in Aroostook as compared with 83-fold outside, and in 1938 mosaic increased 8-fold in Aroostook and Patten as compared with 5-fold outside. Therefore, in general,

roguing and isolation were less successful as to mosaic in Aroostook than outside and less successful as to leafroll outside Aroostook than within.

EARLINESS OF PLANTING, ROGUING, AND PLANT DEVELOPMENT IN SEED PLOTS

In 1933 the plots could be divided roughly into two groups according to the earliness of planting, roguing, and development of the plants. The time of planting did not necessarily determine the rapidity of growth. Roguing was done as soon as the plants were large enough. In the following years the plots were divided into three groups—early, medium, and late. The time of planting ranged, respectively, from May 6 to May 22, May 20 to June 13, and June 2 to July 4, depending upon region and season. As is shown in Table 10, in four comparisons the early plots produced seed stocks with significantly less mosaic than the medium or late plots, and in five instances seed plots of one group produced seed

TABLE 10

Effect of earliness of planting, roguing, and foliage development in the seed plot upon disease in the replanted seed stock

Year	Mosaic				Leafroll				Remarks
	Early[1]	Medium	Late	Significant differences	Early	Medium	Late	Significant differences	
	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent		
1933	0.59	—	2.48	Early vs. late	0.25	—	1.44	Early vs. late	Early plots were larger
1935	0.06	0.68	0.02	Medium vs. early Medium vs. late	0.47	0.01	1.42	Medium vs. late	Medium plots were Aroostook and smaller
1936	0.11	0.74	1.30	Early vs. late	0.10	0.10	0.63		
1937	1.21	4.88	2.75		5.74	9.93	10.56		
1937 Aroostook only	1.41	7.66	8.26	Early vs. late	2.24	11.36	27.27	Early vs. late	
1938	0.05	0.12	0.80		1.33	7.30	6.10	Early vs. medium. Early vs. late	
Averages	0.57	2.82	2.63		1.69	5.74	7.90		

[1] Early plots were planted May 6 to May 22, medium ones May 20 to June 13, and late ones June 2 to July 4.

stocks with significantly less leafroll than a group of later seed plots. Therefore there was a general trend in favor of greater success as the plot was earlier. The averages support this idea somewhat.

EFFECT OF SIZE OF SEED PLOT UPON DISEASE CONTROL

Each seed plot when rogued was measured as to dimensions; later the area was computed. Generally the larger the seed plot, the less mosaic there was in the replanted seed stock (Table 11), but the correlation was never significant. If the seed plots are divided into those below an acre in area and those above, in every case (Table 12) the smaller ones have more mosaic than the larger in the replanted stocks. This difference is not consistent for leafroll. In 1937 there was a difference between small and large seed plots as to the proportion planted tuber-unit, but in spite of the smaller ones being mostly tuber-unit and therefore better rogued, stocks replanted from them showed over twice as much mosaic as the replanted stocks from the larger plots, mostly bulk-planted.

TABLE 11

Effect of size of seed plot

Year	Correlation (r) between area of seed plot and disease percentage in replanted seed stock[1]		Remarks
	Mosaic	Leafroll	
1933	—.349	—.301	
1935	—.316	+.318	Aroostook plots mostly smaller
1936	+.073	+.021	
1937	—.129	—.111	
1937 Aroostook only	—.200	—.236	
1938	—.119	+.083	

[1] No correlation was significant.

In 7 of the 10 comparisons of Table 12, the kind of difference as to disease-content that was present in the seed plots was also present in the corresponding replanted stocks. That is, usually if there was more mosaic in the smaller plots than in the larger plots,

TABLE 12

Effect of size of seed plots on average disease-content of replanted seed stocks

Year	Plots				Disease in seed plots		Disease in replanted seed stocks	
	Range in size	Av. size	No. Total	No. T.u.	Mosaic av.	Leafroll av.	Mosaic av.	Leafroll av.
	Acres	Acres			Per cent	Per cent	Per cent	Per cent
1933	0.20–0.75	0.46	10	7	0.05	0.14	2.21	1.42
	1.0 –2.9	1.76	8	5	0.02	0.34	0.93	0.28
1935	0.20–0.96	0.49	11	4	0.03	0.01	0.51	0.36
	1.07–6.00	2.53	18	8	0.01	0.06	0.04	0.79
1936	0.08–0.95	0.40	13	6	0.01	0.07	0.98	0.16
	1.04–9	2.67	13	6	0.01	0.07	0.78	0.45
1937	0.09–0.93	0.37	11	9	0.04	0.16	4.81	10.39
	1.09–2.52	1.61	16	3	0.02	0.12	2.12	8.13
1938[1]	0.09–0.57	0.27	7	4	0.11	1.36	0.46	7.14
	1.56–5.84	2.55	7	3	0.01	0.26	0.13	3.36

[1] Most of the smaller plots were outside Aroostook, and most of the larger plots were in Aroostook.

the replanted stocks from the smaller plots also had more mosaic than the replanted stocks from the larger plots. The difference often was not proportional and the amount of disease was usually small in the seed plots. However, it is possible that the difference in disease percentage determined somewhat the apparent effect of size of plot upon disease control.

EFFECT OF LOCAL ISOLATION UPON SUCCESS OF SEED PLOTS

When the seed plots were rogued, an examination was made of the nearest other potato fields unless they were more than half a mile distant, and even then sometimes they were examined. In 1933 and 1935 the plots were then classified as having either good, poor, or rather poor isolation. In following years they were classified as having isolation that was good, fairly good, rather poor, or poor. The relationship of this classification to the disease percentages in the replanted seed stocks is summarized in Table 13. Although the differences, with one exception, were not significant, in general there was a trend to greater success in mosaic control as the isolation was better. There was no consistent trend between isolation and success in leafroll control. The mosaic trend was correlated with the poorer isolation in Aroostook County, which

TABLE 13

Effect of local isolation upon success of seed plots

Year	Mosaic with varying isolation				Significant mosaic differences	Leafroll with varying isolation			
	Good	Fairly good	Rather poor	Poor		Good	Fairly good	Rather poor	Poor
	Per cent	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	Per cent
1933	0.87	—	—	2.01		0.62	—	1.66	—
1935	0.02	—	—	0.74	Good vs. poor isolation	0.75	—	—	0.29
1936[1]	0.34	0.91	1.22	1.05		1.09	0.08	0.09	0.00
1937[2]	1.52	1.47	3.05	9.24		6.99	13.24	3.36	13.02
1937 Aroos-took only	2.53	5.13	5.09	9.24		9.70	17.58	5.44	13.02
1938[3]	0.05	0.10	3.10	0.10		7.42	1.38	18.00	1.83
Averages	0.89	1.90	3.12	3.73		4.43	8.07	5.71	5.63

[1] Plots in good-isolation group were all outside Aroostook; plots in poor-isolation group were all in Aroostook.
[2] Plots in poor-isolation group were all in Aroostook.
[3] Plots in poor-isolation group were all in Aroostook; plots in good-isolation and rather-poor-isolation groups were all outside Aroostook.

has been shown to be the region of more difficult mosaic control. Whether the poorer isolation in Aroostook permitted natural agencies such as insects to spread mosaic more, or whether some other regional condition caused the difference, is not known. As to leafroll, apparently the better isolation outside Aroostook was balanced by the greater general spread or increase of leafroll outside Aroostook. The reason for this is not known.

The plots with disease known to enter them or be eliminated from them (Table 3) were studied further with respect to the records on proximity of diseased fields. A proximity index was determined by dividing the percentage of the disease in nearby fields by the distance in centuries (hundreds) of feet from the seed plot. For example, a field 8 per cent mosaic and 500 feet distant would have a proximity index of 8/5 or 1.6; a field 50 per cent mosaic and 200 feet distant would have a proximity index of 50/2 or 25.0; and a field 2 per cent mosaic 2,000 feet away would have a proximity index of 2/20 or 0.1. It may be remembered that State certification is not allowed if a field of 3 per cent is only 250 feet away (*23*, pp. 2-3); this combination gives an index of 3/2.5 or 1.2.

The proximity index for mosaic averaged as follows:

43 plots healthy but contracting mosaic............3.92
30 plots remaining free of mosaic...............0.62
10 plots losing their mosaic.....................0.56

Therefore the proximity index was by far the highest for the first class of plots, namely, those invaded by mosaic. Among the plots of this class there was some correlation between the index and the mosaic percentage (r = +.130, not significant). However, individual plot variation was such that the 36 plots with mosaic entering up to 2.8 per cent (below certification tolerance) had proximity indices of 0 to 30.6 while the 7 plots with enough mosaic entering to equal or exceed the certification tolerance (3.0 per cent) had proximity indices of 0.3 to 17.0. Therefore the proximity index of the seed plot was a poor guide to certifiability of the replanted stock.

It is interesting to compare the noncertifiable replanted stocks with the certifiable ones, with respect to the guidance furnished by the isolation requirement (*23*; pp. 2-3). Only 2 (29 per cent) of the 7 plots with too much mosaic in the replanted stocks would have been disqualified by the certification proximity rule, and 7 (19 per cent) of the other 36 plots, with replanted stocks certifiable, would have been similarly disqualified. Therefore the certification proximity requirement was not a safe guide to the amount of mosaic entering these healthy plots.

The proximity index for leafroll averaged as follows:

17 plots healthy but contracting leafroll...........0.83
11 plots remaining free of leafroll...............0.11
11 plots losing their leafroll....................0.07

Therefore, as for mosaic, the proximity index was much higher for the leafroll-acquiring class of plots than for the others. Among the plots of the first class, however, there was only negative correlation between the index and the leafroll percentage (r = —.121). Two healthy plots with the highest proximity indices of 4.0 and 9.0 respectively acquired leafroll in only 0.1 per cent, while three plots with no leafroll potatoes within 7,000 feet contracted 2.8, 5.0, and 34.8 per cent leafroll respectively. Therefore apparently

leafroll was sometimes being spread for miles to healthy plots, while at other times transmitting agencies if present did not take advantage of an apparent golden opportunity to spread the disease a short distance. Complete information on insect conditions probably would explain such differences.

COMBINATIONS OF CONDITIONS

Since there was a tendency to more mosaic in the replanted stocks following tuber-unit planting, greater distance from Kittery,

TABLE 14

Combinations of conditions with significant effect upon success of seed plots

Disease	Year	Conditions: Planting		Region		Development		Plot size		Isolation		Disease percentage
		T.u.	Bulk	N.E.	S.W.	Medium & late	Early	Small	Large	Poor	Better	
Mosaic	1937	x		x								5.94
			x		x							0.00
	1937	x		x				x				7.56
			x		x				x			0.00
	1937			x				x				7.10
					x				x			0.0011
	1937			x				x		x		7.85
					x				x		x	0.014
	1937			x						x		7.68
					x						x	0.001
	1933					x		x				2.93
							x		x			0.62
	1937–A[1]					x		x		x		9.79
							x		x		x	0.20
	1937					x				x		6.70
							x				x	0.12
	1937–A					x				x		8.93
							x				x	0.15
Leaf-roll	1938				x			x				7.88
				x					x			1.33
	1938				x	x		x				7.88
				x			x		x			1.33
	1938				x	x						8.97
				x			x					1.33
	1933					x		x				1.94
							x		x			0.28
	1938					x		x				7.14
							x		x			1.33
	1937–A					x					x	20.58
							x			x		1.22

[1] "–A" denotes in Aroostook only.

lateness, smallness of area, and poor isolation in the seed plots, a study was made of the apparent effects of these conditions in various combinations. Significant differences between averages were difficult to find because of the small number of plots characterized by any one combination of conditions. Those disclosed are listed in Table 14. For example, mosaic averaged 5.94 per cent in the replanted seed stocks from the 1937 seed plots that were tuber-unit and in the northeast, while it was absent in the replanted seed stocks from the 1937 seed plots that were bulk-planted and in the southwest. In the 9 mosaic comparisons with significant differences, 5 included the northeast region, 4 included medium and late development, 5 included smallness, and 5 included poor isolation as conditions favoring the higher percentage of mosaic.

Since there was a tendency to more leafroll in the replanted stocks with less distance from Kittery, lateness, and smallness of seed plot, these conditions were combined in the study of their effects. In the 6 leafroll comparisons with significant differences (Table 14), 3 included the southwest region, 5 included medium and late development, and 4 included smallness of seed plot as conditions favoring the higher percentage of leafroll.

CORRELATION BETWEEN MOSAIC AND LEAFROLL

In the replanted seed stocks from the seed plots of 1933, 1935, and 1936, there was no consistent or significant correlation between

TABLE 15

Correlation between mosaic and leafroll in seed plots and replanted seed stocks

Year of seed plots	Source of figures	r
1933	Replanted seed stocks	+.372, not significant
1935	Ditto	—.170, not significant
1936	Ditto	+.059, not significant
1937	Seed plots Replanted seed stocks	+.254, not significant +.761, highly significant
1937 Aroostook only	Seed plots Replanted seed stocks	+.081, not significant +.877, highly significant
1938	Seed plots Replanted seed stocks	—.099, not significant +.578, significant

mosaic and leafroll (Table 15). However, in 1937 and 1938 there was a significant positive correlation between mosaic and leafroll percentages in the replanted seed stocks although the seed plots had not shown a consistent or significant correlation between the two diseases. The explanation for correlation or lack of it is not apparent.

GENERAL CONCLUSIONS FROM FARMERS' SEED PLOTS 1933 TO 1938

The success of farmers' seed plots varied from year to year and the effect of various conditions also changed from one season to another. On the whole, the general trend of the results from 114 plots grown 1933 to 1938 on 74 different farms (Fig. 1) was as follows:

(1) Mosaic and leafroll entered seed plots frequently, but yellowtop and spindle tuber entered seed plots rarely. Mosaic and leafroll usually increased in spite of roguing or came in where they had been absent, while spindle tuber decreased when present and yellow top mostly disappeared if present.

(2) The rate of increase of mosaic and leafroll as expressed in the average percentage for the seed plots of one year *vs.* the average percentage for the replanted seed stocks in the next year was influenced more or less by several conditions.

(3) Although tuber-unit planting of the seed plot permitted more nearly complete roguing than did bulk planting, the former was associated more with the entrance of disease into healthy plots and was associated with more disease, especially mosaic, in the replanted seed stocks. This was due to other associated factors being more determinative of seed-plot success.

(4) Disease-content in the seed plot influenced disease-content in the replanted stocks positively and significantly in some years.

(5) It was found that usually the further north and east from Kittery a seed plot was planted, the more likely would be an increase in mosaic and the less likely there would be an increase in leafroll.

(6) Earlier planting and earlier development of the plants

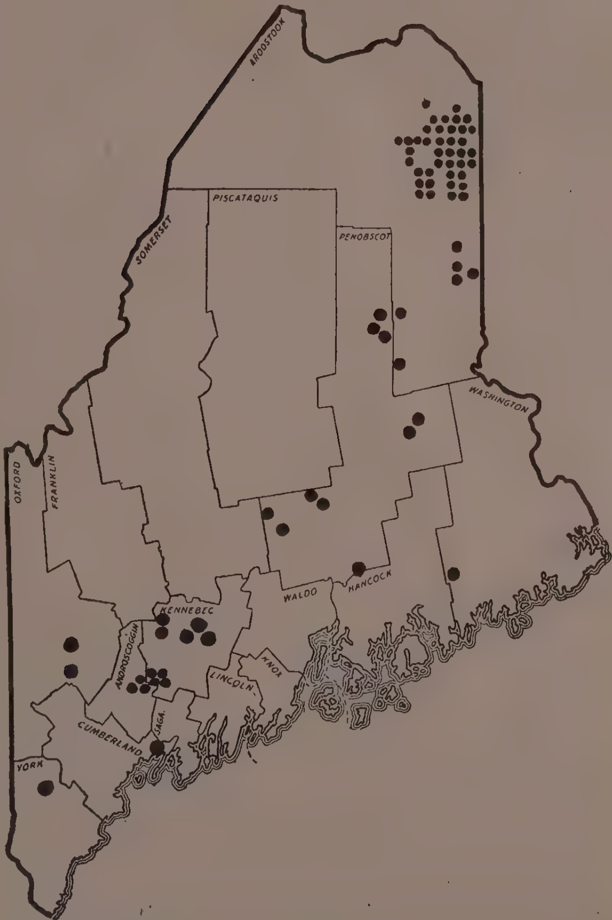

FIG. 1. Location of 74 farms where one or more Green Mountain tuber-line seed plots were grown 1933 to 1938.

were factors which improved the chances for success in disease control.

(7) The larger the seed plot, the less mosaic there was in the replanted seed stock.

(8) Mosaic was controlled better as comparative isolation from mosaic in other fields was better. The certification proximity rule was not a safe guide as to the amount of disease entering healthy plots.

(9) Mosaic increase was correlated significantly with leafroll increase in two years but not in three other years.

FIELD OBSERVATIONS ON INSECTS

In the previous part of this bulletin it has been shown that usually leafroll was brought into the Highmoor Farm seed plot more than mosaic and yellowtop, that the extent of the introduction of a given disease was not the same during different seasons, and that the part of the State represented by Highmoor Farm generally showed more leafroll increase in the farmers' seed plots than did the northeastern part of the State. Differences of this kind had been expected on the basis of previous observations. It also had been expected that their explanation might be found in certain variations in insect populations.

During the years 1925 to 1930, therefore, insect counts of various kinds were made at Highmoor Farm in connection with seed plots or with fields containing small plot sections planted 100 per cent mild mosaic, rugose mosaic, leafroll, spindle tuber, and giant-hill.[6] The kinds of insects found on potato plants or tubers in two published lists (*14; 13*) had numbered about 100. A review of a dozen or more other articles had added about 40 other species. It was thought that the season-to-season variation of some of these 140 or so kinds of insects might be correlated with variation in the spread of a virus disease in such a way as to indicate the importance of that insect with respect to virus spread.

Three simple methods of insect counting were used: (1) sweeping 200 feet of the length of a potato furrow with a net 15 inches wide, sampling first one side or row of plants and then another; (2) shaking each of 10 plants quickly when bending it over in the opening of the net; (3) removing carefully and examining immediately each of 50 leaves, consisting of 5 per plant taken

[6] Plot sections with the various diseases were planted in the four corners and the middle, respectively, of a healthy field.

respectively from 5 horizontal zones of the plant, namely, at top, near top, near middle, near soil, and at soil, from 10 plants. The first two methods disclosed the presence of certain active insects that were not found with the third method, and aphids and other sluggish insects that stuck to the plant were counted best by means of the third method.

During the years 1924 to 1933, tuber-unit plots were rogued on Highmoor Farm with varying degrees of success with respect to the control of virus diseases. From 1927 to 1930, healthy-appearing hills were dug at different dates and at different distances from the small plot sections that were respectively 100-per cent mild mosaic, rugose mosaic, leafroll, spindle tuber, and giant-hill. The spread each year, as shown by the progeny grown the following summer, was as shown in Table 16.

TABLE 16

Spread of virus diseases from affected plot sections to healthy parts of the same field

Disease	Spread to healthy plants in different years			
	1927	1928	1929	1930
Mild mosaic	Early	2 per cent	Close	Close, early
Rugose mosaic	Early	28 per cent	Far, early	Close, early
Leafroll	Late	52 per cent	Far, early	Close, late
Spindle tuber	Late	6 per cent	Close, late	Close, late
Giant-hill[1]	—	None	None	None

[1] Not proved to be a virus disease.

Evidently no two of these diseases acted alike in this disease-including field for two consecutive years, except the nonspreading giant-hill. For example, although mild mosaic and rugose mosaic both spread early to healthy hills in the 1927 plot, in 1928 the former spread to only 2 per cent of the sampled healthy hills and the latter to 28 per cent. Again, although rugose mosaic and leafroll both spread to healthy hills early and far in the 1929 plot, in 1930 the former spread early only to nearby hills while the latter spread late to nearby hills. The insect counts therefore were of interest in an attempt to correlate the spread of one or another disease with the abundance of one or another insect species. The effectiveness

of roguing in seed plots is, of course, often partly dependent upon the earliness of spread of virus diseases.

Flea beetles (*Epitrix cucumeris* Harris)[7] were abundant early in rogued plots in 1925, 1926, 1927, and 1928, but regardless of their abundance leafroll was reduced by roguing in 1926 and 1928. Colorado potato beetles (*Leptinotarsa decemlineata* Say) were present during the roguing of leafroll in 1925, 1928, and 1929, with the disease nevertheless being reduced in 1928. Apple leafhoppers (*Empoasca mali* LeBaron) were present in 1928 during the roguing of leafroll but with the disease nevertheless being reduced. These leafhoppers were more abundant in the disease-including field in 1927 and 1929 than in 1928 but with no corresponding differences in spread of any of the four virus diseases, mild mosaic, rugose mosaic, leafroll, and spindle tuber. Tarnished plant bugs (*Lygus pratensis* Linn.) were present during the roguing of leafroll in 1928 and 1929 but with the disease being reduced in 1928. These bugs were comparatively abundant (30 to 45 per 10 plants or per 100 feet of row), in the plot containing diseased sections, in 1928 and 1929, which were seasons of the least spread of mild mosaic and rugose mosaic. Further, there was but little more leafroll spread in 1929 than in 1927—a year when these bugs were scarce (5 per 100 feet of row). Aphids were not found during the roguing of leafroll in 1926, with the disease being reduced; both these happenings were rare in this work and their coincidence may be due to a cause and effect relationship.

SMALL-CAGE EXPERIMENTS WITH INSECTS

The preceding studies were accompanied by leafroll inoculations in small cloth insect cages (*17*, Plate 8), each holding three potato plants. In some instances healthy Green Mountains were grown inside the cages with leafroll Bliss Triumphs just outside so that the roots of the two varieties would grow intermingled. In other cases a leafroll Bliss Triumph plant was grown inside the cage between healthy Mountain plants. The insects were transferred to healthy plants after they had fed on leafroll plants, or

[7] Insect identifications were confirmed by Dr. Edith M. Patch, Entomologist.

were allowed to feed at will in cages containing both healthy and leafroll plants. The complete results of the inoculations and exposures were, of course, manifested only by the amount of disease perpetuated in the tubers of inoculated plants and appearing early in the second generation of plants. These plants were grown in the open on Aroostook Farm, where leafroll spread very little if at all during the years involved.

Root contact between diseased and healthy plants did not transmit leafroll from the diseased to the healthy plants in 8 root-contact tests in 1927, in 6 in 1928, or in 6 in 1929. These 20 tests were all that were made of this kind. Contact of both roots and shoots, with or without the presence of certain kinds of insects, not aphids, produced no infection in the 34 plants thus exposed in 1930 or in the 24 plants exposed in 1931.

Flea beetles did not transmit leafroll. After they had fed on diseased plants they were introduced into cages containing only 3 healthy plants apiece in these respective numbers of beetles per cage:

(1927) 12 and 120 beetles per cage, respectively
(1928) 75, 180, and 200 beetles per cage, respectively
(1929) 60, 100, and 200 beetles per cage, respectively

They were introduced into the mixed (leafroll and healthy) cages in these respective numbers per cage:

(1930) 100 and 150 beetles per cage, respectively
(1931) 160 and 250 beetles per cage, respectively

In these instances the development of many flea-beetle holes in both kinds of plants showed that the insects had dispersed and eaten freely.

Adult Colorado potato beetles were introduced into only one healthy 3-hill cage (17 insects, in 1928). They did not transmit leafroll.

Apple leafhoppers did not transmit leafroll when introduced into healthy-plant cages as follows:

(1927) 11 and 40 per cage, respectively
(1929) 7, 30, 33, and 45 per cage, respectively

Tarnished plant bugs did not transmit leafroll when introduced into healthy-plant cages as follows:

(1928) 10 and 19 per cage, respectively
(1929) 10 per cage

Or when they were introduced into the mixed cages as follows:

(1930) 8, 21, and 31 per cage, respectively.

These results confirm certain negative unpublished results obtained in the Orono greenhouse 1921-22 when 10, 12, and 14 such bugs per plant, respectively, were introduced to plants one inch high.

The pink and green potato aphid (*Macrosiphum solanifolii* Ashm.)[8] did not transmit leafroll under some conditions, such as when introduced into cages in the following amounts:

(1928) 3 aphids per cage
(1929) 3, 6, 21, 50, 500, 600, and 3,000 aphids per cage, respectively
(1930) 150 and 300 aphids, respectively, per cage to large, early-planted hills
(1931) 12, 80, and 150 aphids, respectively, per cage.

Also, no infection resulted from inoculating a few hills in the open field with 5,000 aphids of this species.

On the other hand, this species did transmit leafroll when introduced as follows:

(1930) 150 and 300 aphids, respectively, per cage to small, late-planted hills
(1930) 500 per cage to large, early-planted hills
(1931) 500 and 1400 aphids, respectively, per cage

The differences shown with this species of insect with respect to size and earliness of plants offer some explanation of the fact that earliness of planting and of development of the plants in the seed plots acted against the increase of leafroll in the plots. As previously shown, the disease-checking effects of tuber-unit planting and local isolation were reduced or nullified when these two factors were

[8] Data for aphids include only those where pure populations originating from single individuals were used.

associated with smallness of plot and lateness of planting. As was also shown, when tuber-perpetuated disease was present and was early-rogued, such disease was much less important than invasion of the plot by disease and the spread of disease within the plot after invasion. Now, the later the planting of a plot, the smaller would be the plants when aphids begin carrying disease from one field to another, and, according to the cage experiments just described, the more plants there would be that were infected by a given number of aphids per plant. If there were a comparatively small number of aphids entering a plot from diseased fields, the smaller the plot the more aphids there would be per plant. This also, according to the cage experiments, would cause the aphids to infect a larger percentage of the plants.

The spinach or peach aphid (*Myzus persicae* Sulz.) did not transmit leafroll when used as follows:

(1927) 10,000 aphids per cage (killing the plants too soon to permit the virus to reach the tubers)
(1929) 2 aphids per cage

This species was not tested much here because it already was well-known to be a very effective transmitting agent.

The buckthorn aphid (*Aphis abbreviata* Patch) did not transmit leafroll when used as follows:

(1928) 400 and 500 aphids per shoot, respectively
(1930) 20,000 aphids to a few hills in the open field
(1931) 40 and 130 aphids per cage, respectively

This species did transmit leafroll when used:

(1931) 250, 350, 450, 1,000, and 1,500 aphids per cage, respectively

DISCUSSION ON INSECTS

From these various studies made with rogued seed plots, fields containing diseased plots, and small cages, it appears that aphids were more important in the transmission of virus diseases than were certain other kinds of insects that were common in one year or another. This conclusion is in agreement with those of Dykstra

and Whitaker, who also obtained negative results with flea beetles, tarnished plant bugs, and leafhoppers *(2)*. The positive results of other experimenters *(2)* may be of importance, however, in non-rogued fields under certain conditions. It may be pointed out also that many factors involving field spread of potato virus diseases remain to be studied, including variety of potato, susceptible weeds, stage of diseased plant, environment of diseased plant, length of time of feeding on diseased plant, stage and age of insect transferred, age of inoculated healthy plant, environment of inoculated plant, incubation period in insects, manner of transfer or of movement of insect, number of insects transferred or moving, place of feeding on inoculated plant, duration of feeding on inoculated plant, size of inoculated plant, and variation in individual insects in ability to transmit.

Further, insects of certain species may be relatively scarce and yet they may be very effective in transmitting a virus disease, thus having importance much greater than their numbers would indicate. Incidental to the counts of the more abundant kinds of insects known to feed on potato plants, collections were made of insects found on potato plants. There were about 50 different species each year in 1927, 1928, 1929, and 1930.[9] Part of these are not feeders on potato plants. Possibly others were present and were feeders but were not caught for collections. There are at least a dozen available reports of work showing that one individual insect of a species can transmit a disease, such as potato leafroll, tobacco mosaic, cucumber mosaic, tulip breaking, passion-fruit woodiness, "pea virus 2," celery western mosaic, strawberry crinkle, aster yellows, beet curly-top, rice stunt, pineapple yellow-spot, celery yellows, and maize streak. One report lists ten species of aphids in each one of which it was found that single insects were capable of transmitting western-celery-mosaic (*18*, pp. 528-529). Any insect species with a high proportion of individuals able to transmit disease may be much more important than other species with a low proportion capable of acting as vectors.

In 1932, roguing of leafroll was completed in four tuber-unit tuber-line plots on Highmoor Farm by July 12. The aphid count at this time was none for 50 leaves on 10 plants, and had been no

[9] Number confirmed by Dr. Frank H. Lathrop, Entomologist, by examining the collections.

more than 2 at any previous time. Yet the records of 1933 showed leafroll increase as follows:

Line	10	301	302	303
Leafroll percentage in seed plot in 1932	0.1	1.7	1.9	0.1
Leafroll percentage in replanted seed stock in 1933	0.05	2.2	0.2	0.25

Thus without any apparent explanation, leafroll increased in two tuber-lines and decreased in the others.

After 1932, most of the Highmoor Farm work on potato virus diseases was involved with the tuber-line plots as described previously in this bulletin. Some of them were used in the aphid studies reported in Bulletin 403 *(20)*, which includes some important conclusions as to the causes of infection entering healthy plots (*20*, pp. 219, 222, 226, 228, 229, 249, 250, 251, and 252). The writer of the present bulletin did not attempt to venture into this phase of the problem, except to provide the instances, described in preceding sections of this bulletin, of virus diseases entering many healthy tuber-line plots. This would have been impossible to demonstrate except by use of the Highmoor Farm tuber-lines or large stocks kept healthy at Highmoor Farm by virtue of large cloth cages and unusually good isolation.

SUMMARY

Potato seed-plot work begun in 1921 and based upon virus-disease discoveries made at about that time, has been continued in Maine to the present time with emphasis by the writer in recent years on aster-cloth cages and tuber-line seed plots. From 1927 to 1932 at Highmoor Farm, 21 tuber-line seed plots grown in the open were invaded by one or another of the virus diseases present in other potatoes on the same farm, in 15 out of 75 possible chances. Such invasion was made by mild mosaic, rugose mosaic, leafroll, spindle tuber, and yellowtop in spite of isolation of at least ¼ mile. From 1933 to 1938, 114 tuber-line seed plots were grown on 74 different farms (Fig. 1), with a follow-up inspection of the progeny during the following year in each instance to disclose what virus diseases had been brought into the seed plot by insects and to what extent.

The 114 farmers' seed plots mostly were planted with seed directly from Highmoor Farm seed plots, which after 1933 were planted with seed from an aster-cloth cage. The cage excluded virus diseases perfectly or, when erected a little after some plants had emerged from the soil, almost perfectly. Invasion of open plots by leafroll and mosaic was generally much less on Highmoor Farm than elsewhere, while yellowtop entered more often at Highmoor Farm. Mosaic (mostly mild) entered at least 43 plots and did not enter 40 plots. Leafroll entered at least 17 plots and did not enter 22 plots. The average proximity to diseased fields was much greater for the 43 than for the 40, and for the 17 than for the 22, but the amount of disease entering the 43 and the 17 was not indicated reliably by the degree of proximity. Yellowtop entered at least 3 plots and did not enter 105. Spindle tuber entered one plot while not entering 108.

The farmers' seed plots were invaded by mosaic and leafroll to different degrees according to the season and other factors. In 1937, leafroll increased to an unusually large extent in both Aroostook and other counties, while mosaic increased to more than the usual extent in Aroostook but decreased in an unusually large proportion outside of Aroostook. Mosaic and leafroll usually increased in spite of roguing or came in where they had been absent. Spindle tuber decreased when present, and any yellowtop mostly disappeared. Tuber-unit planting of seed plots permitted more nearly complete roguing than bulk planting, but was associated more with the entrance of disease into healthy plots and was associated with more disease, especially mosaic, in the replanted seed stocks. As seed plots were situated further northeast in the State, the replanted seed stocks had more mosaic and less leafroll. In some years the more disease in the seed plot, the more in the replanted stock. In some years the more mosaic increased, the more leafroll did also. The larger the seed plot or the better isolated it was, the less mosaic there was in the replanted seed stock. Earlier planting and earlier development of the plants in the seed plot increased the possibility of success in disease control. The certification proximity rule was not a safe guide as to the amount of disease entering healthy plots.

Insect counts in the field, samplings of healthy stocks near diseased plants, and insect transfers in cages were made at High-

moor Farm in an effort to explain virus invasion of healthy tuber-line plots and virus spread after invasion. Giant-hill did not spread. Two species of aphids (*Macrosiphum solanifolii* Ashm. and *Aphis abbreviata* Patch) transmitted leafroll under some experimental conditions, while other insects (flea beetles, Colorado potato beetles, apple leafhoppers, and tarnished plant bugs) and root contact in the soil did not. Insect counts in the field indicated that the latter insects (excluding aphids) were not important in the field spread of leafroll and other virus diseases. However, such work as has been done so far indicates that when the many unsolved problems in this field of research are studied, present conclusions may have to be modified.

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PLATE 1. Potato sport plants of partly sport tuber-line found in 1930 in a Highmoor Farm Green Mountain tuber-line. Leaves deformed, crinkly, and somewhat lacking in hairs. See Plates 2 and 3.

Plate 2. Normal potato plants descended from sport plants of partly sport tuber-line represented in Plate 1. See Plate 3.

PLATE 3. Middle row, sport plants of a partly sport tuber-line originating in 1930 in a Highmoor Farm Green Mountain tuber-line. (See Plate 1.) Left, normal part of partly sport tuber-line. Right, normal progeny of sport plants of partly sport tuber-line. (See Plate 2.) The sport plants yielded 18 per cent less than the normal plants.

PLATE 4. Tuber-line Green Mountain potatoes inside Highmoor Farm aster-cloth cage.